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Groundwater Prospect in a Typical Precambrian Basement Complex using Karous-Hjelt and Fraser Filtering Techniques

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ABSTRACT

Electromagnetic survey was carried out at Ibodi, village, Ilesa in Atakunmosa West Local government area with a view to determining the probable locations for groundwater exploration in the study area. Ibodi falls within latitude $7^0\ 35'\ 35.21''$ North and longitude $4^0\ 40'\ 48.28''$ East. The development and increase in immigrants at Ibodi has necessitated this study. A total of five profiles from North to South directions were occupied. It was discovered that distances (100.0-140.0) m, 40.0 m, 80.0 m and 35.0 m on profiles 1, 3, 4 and 5 respectively revealed fractured zones which are suspected to be the best locations for groundwater prospects in the study area.

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INTRODUCTION

The availability of sufficient, safe and affordable water is vital for human development [12]. This is fundamental as it is one way of eliminating poverty in a given community since time is freed up to focus on income generating activities rather than fetching for clean and safe water. According to the [22,24,11], there are more than 1.2 billion people who lack access to adequate supply of safe and clean water.

The adoption of the Human Right approach to water was to put the peoples' need first regarding water use and to promote human-centered water resource development based on a coherent framework of binding legal norms and accountability. The term 'human rights' refers to those rights that have been recognized by the global community in the Universal Declaration of human rights, adopted by the United Nations (UN) member states in 1948, and in subsequent international legal instruments binding on states. The human rights approach is especially used to challenge the economic and social injustice. The consensus on human rights reflects a global moral conscience [25].

The adoption of the Millennium Development Goals (MDGs) sets water as one of its specific targets to achieve. The 1992 Dublin Water Conference, Principle 4 states that, "water has an economic value in all its completing uses and should be recognized as an economic good" [5]. The rational for the emergence of water as a human right stems from the need to secure water for the poor and marginalized people and to urge governments to address the water agenda as a national priority as outlined in the MDGs [12].

The traditional methods of water exploitation in Nigeria consist of (1) direct collection of rain water with pots, guards and other containers and (2) extraction from springs, streams, ponds and wells. Water shortages during the dry season are quite common as many of these sources dry up. People then have to trek long distances in search of water. Apart from the problem of irregular water supply from these sources, there is the problem that the water is untreated and therefore carries organisms parasitic to man.

It is not often realized, except in times of shortages and drought, that water is a unique resource that has no substitute. It is high time we stopped regarding water as an inexhaustible gift of nature. Water has to be transformed from its natural raw state and then transported to our homes and factories to satisfy man's needs because the hydrologic cycle does not adapt itself to our space, time and quality requirements. The accelerating growth of human population, the rapid advances made in industries and agriculture have resulted in a rapidly increasing use of water by man, to the extent that the availability of water, as well as the control of excessive water, has become a critical factor in the development of the world [3].

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Of all the natural resources, water permeates perhaps most deeply into all aspects of life. Water is no doubt one of the most essential needs of human beings, for drinking and other domestic purposes. Its presence or lack of it determines to a great extent the nature of the natural environment in which life and majority of our economic activities depend on. Water availability is governed by the water cycle, in which rainfalls from the clouds flows over the land or sinks through the ground, where it may be stored as groundwater in underground aquifers, and finally flows through rivers, lakes and dams towards the sea. Evaporation from surface water and transpiration of plants and trees feed the clouds and the cycle continues [2].

The supply of potable water in Nigeria is almost entirely restricted to the urban centers and other major towns. The rural areas rarely benefit from such supply. It not surprising therefore that the rural areas are often ravaged by water borne diseases such as typhoid, cholera and guinea worm. In an attempt to make potable water available to the rural communities in Nigeria, effort needs to be made in developing groundwater through the drilling of boreholes. Drilling of productive water borehole depends to a large extent on the pre-drilling geophysical survey employed in locating the suitable site of the borehole.

Electromagnetic (EM) profiling is a widely used geophysical method in the delineation of basement regolith and location of fissured media and associated zones of deep weathering in crystalline terrains [4,10,17,19]. Electromagnetic method also constitutes the most reliable means, outside direct mechanical drilling, through which basement structures such as ancient river channels, basement depressions and fractured zones that are of hydrogeological significance can be mapped [7,23]. EM response in basement complex area as observed by Olorunfemi et al, [18] is strongly influenced by the conductive weathered zone. A very conductive weathered layer will give high amplitude EM response with usually negative polarity. Ibodi village, Ilesa in Atakunmosa West Local Government Area was chosen for this study because there will be increase in population of the people living at Ibodi due to the plan in 2013 to construct an infantry battalion barracks at Ibodi in Osun State by the Federal Government of Nigeria. The barracks is expected to accommodate a minimum of 700 soldiers which might lead to influx of people in the study area. Precambrian basement complex without fractured zones has been known to be unproductive for groundwater exploration while aquifers are found in the fractured zones, therefore this study will reveal some probable zones which are good for groundwater exploration in the study area.

Geology of The Study Area:

Ibodi Village, Ilesa, Nigeria is located on the crystalline basement complex (figure 1). It falls within latitude $7^0\ 35'\ 35.21''$ North and longitude $4^0\ 40'\ 48.28''$ East. Regionally the area under investigation is concealed with the Southwestern Nigeria basement complex composing migmatite-gness complex, metaigneous rock such as pehtic schist, quartzite, amphibolites, charnokitic rocks, older granite and unmetamorphorsed dolerite dykes. The rock sequence consists of basically weathered quartzite older granite. The basement complex rocks of Nigeria are made up of heterogeneous assemblages [20].

The basement complex rock in their unaltered forms is generally characterized by low porosity values usually less than one percent and permeability values that are almost negligible Rahaman [20]. The groundwater potential of such area is therefore dependent on the following factors; the presence of large fractures, joins or brecciate zones within the rock, the extent of weathered overburden and degree or amount of precipitation recharging the aquifer. By far most significant factor in the groundwater capacities of an area underlain by crystalline rock is the depth of weathering. The absolute depth of weathering has implications on the zone of saturation because groundwater is known to fill the regolith from phreastic surface down to the bedrock. The study area falls within the Guinea Savannah belt of Nigeria but exploitation and other human activities have gradually changed the vegetation to that of Sudan Savannah.

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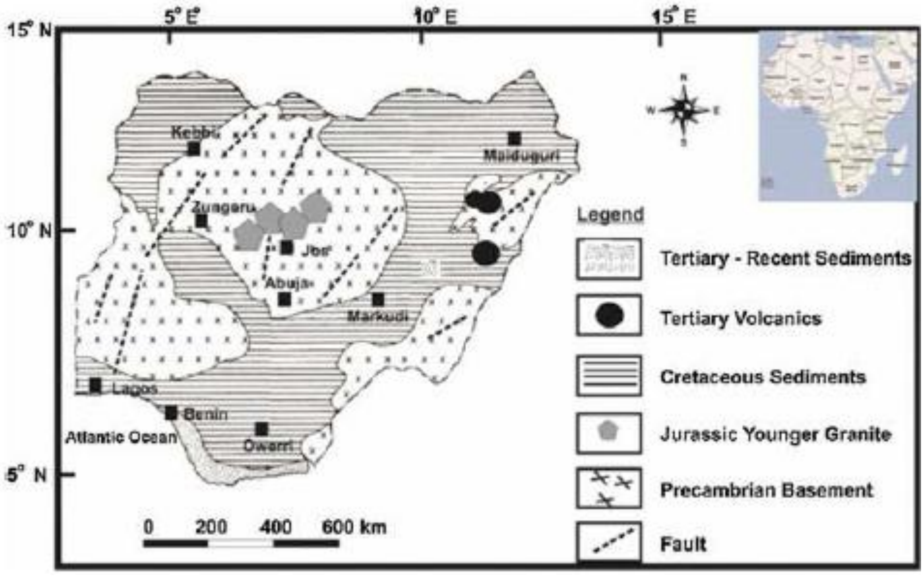

Fig. 1: Geological map of Nigeria [1].

Principle of Electromagnetic Survey:
Very Low Frequency Technique:

Very low frequency (VLF) survey methods rely on eleven major stations that transmit continuous VLF electromagnetic waves distributed throughout the world. The interaction of the electromagnetic plane waves emitted from these transmitters can be measured as the waves impinge on different material conductors in the earth. Vertical sheet conductors are particularly sensitive to the waves. Examples of vertical sheet conductors include faults, dykes and fracture or joint zones. These features are often associated with enhanced fluid (groundwater) flow. Survey profile lines conducted perpendicular to the conductors show a strong response to the conductor. The method is generally inexpensive with final data output from the instrument providing a direct indication of linear conductor anomalies.

Skin Depth:

In electromagnetic methods, the electrical conductivity of the earth plays a pivotal role in the penetration that can be obtained. Conductivity removes (attenuates) energy from the EM wave through the work done by moving voltage. Higher frequency EM waves lose energy more quickly than low frequency waves because, conceptually at least, they move more in a given time. The depth at which a plane electromagnetic wave will be attenuated to (0.37) of its surface amplitude is called the skin depth. The usefulness of the skin depth concept is that it represents the maximum penetration of an EM method operating at frequency f in a medium of conductivity σ. The actual exploration depth may well be much less than a skin depth owing to other factors, notably the geometry of the prospecting system.

Depth of Penetration of Electromagnetic Fields:

The depth of penetration of an electromagnetic field, Spies [21] depends upon its frequency and the electrical conductivity of the medium through which it is propagating. Electromagnetic fields are attenuated during their passage through the ground, their amplitude decreasing exponentially with depth. The depth of penetration d can be defined as the depth at which the amplitude of the field A_d is decreased by a factor e^{-1} compared with its surface amplitude;

$$A_o\, A_d = A_o e^{-1} \qquad (1.1)$$

In this case,

$$d = 503.8\ (\sigma f)\ ½ \qquad (1.2)$$

where d is metres, the conductivity of the ground σ is in Sm^{-1} and the frequency f of the field is in Hz.

The depth of penetration thus increases as both the frequency of the electromagnetic field and the conductivity of the ground decrease. Consequently, the frequency used in an EM survey can be tuned to a

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desired depth range in any particular medium. For example, in relatively dry glacial clays with a conductivity of 5 x 10^{-4} Sm^{-1}, *d* is about 225 m at a frequency of 10k Hz.

Equation represents a theoretical relationship. Practically, an effective depth of penetration z_e can be defined which represents the maximum depth at which a conductor may lie and still produce a recognizable electromagnetic anomaly.

$$z_e = 100\ (\sigma\ f)^{-1/2} \tag{1.3}$$

The relationship is approximate as the penetration depends upon such factors as the nature and magnitude of the effects of near-surface variations in conductivity, the geometry of the subsurface conductor and instrumental noise. The frequency dependence of depth penetration places constraints on the EM method. Normally, very low frequencies are difficult to generate and measure and the maximum penetration is of the order of 500 m.

Depth of Penetration and Current Density:

Eddy currents are closed loops of induced current circulating in planes perpendicular to the magnetic flux (figure 2). They normally travel parallel to the coil's winding and flow is limited to the area of the inducing magnetic field. Eddy currents concentrate near the surface adjacent to an excitation coil and their strength decreases with distance from the coil as shown in the image. Eddy current density decreases exponentially with depth. This phenomenon is known as the skin effect.

The skin effect arises when the eddy currents flowing in the test object at any depth produce magnetic fields which oppose the primary field, thus reducing the net magnetic flux and causing a decrease in current flow as the depth increases. Alternatively, eddy currents near the surface can be viewed as shielding the coil's magnetic field, thereby weakening the magnetic field at greater depths and reducing induced currents.

The depth that eddy currents penetrate into a material is affected by the frequency of the excitation current and the electrical conductivity and magnetic permeability of the specimen. The depth of penetration decreases with increasing frequency and increasing conductivity and magnetic permeability. The depth at which eddy current density has decreased to 1/e, or about 37% of the surface density, is called the standard depth of penetration (d). The word 'standard' denotes plane wave electromagnetic field excitation within the test sample (conditions which are rarely achieved in practice). Although eddy currents penetrate deeper than one standard depth of penetration, they decrease rapidly with depth.

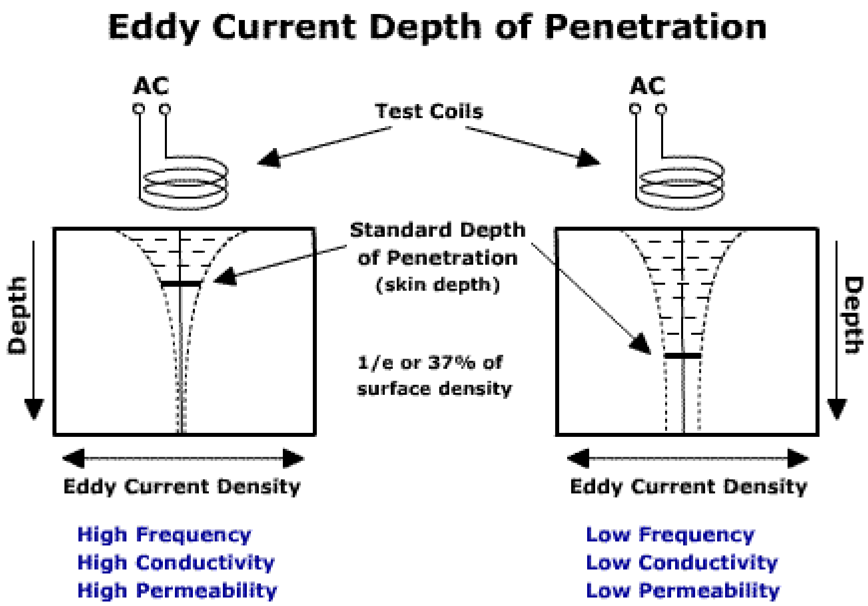

Fig. 2: Depth of penetration and current density

At two standard depths of penetration (2d), eddy current density has decreased to 1/e squared or 13.5% of the surface density. At three depths (3d), the eddy current density is down to only 5% of the surface density. Since the sensitivity of an eddy current inspection depends on the eddy current density at the defect location, it is important to know the strength of the eddy currents at this location. When attempting to locate flaws, a frequency is often selected which places the expected flaw depth within one standard depth of penetration. This

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helps to assure that the strength of the eddy currents will be sufficient to produce a flaw indication. Alternately, when using eddy currents to measure the electrical conductivity of a material, the frequency is often set so that it produces three standard depths of penetration within the material. This helps to assure that the eddy currents will be so weak at the back side of the material that changes in the material thickness will not affect the eddy current measurements.

The applet below illustrates how eddy current density changes in a semi-infinite conductor. The applet can be used to calculate the standard depth of penetration. The equation for this calculation is:

$$\sigma \approx \frac{1}{\sqrt{\pi f \mu \sigma}} \tag{1.4}$$

Basic Concept of Very Low Frequency (VLF) method:

The VLF method uses powerful remote radio transmitters set up in different parts of the world for military communications [14]. In radio communications terminology, VLF means very low frequency, about 15 to 25 kHz. Relative to frequencies generally used in geophysical exploration, these are actually very high frequencies. The radiated field from a remote VLF transmitter, propagating over a uniform or horizontally layered earth and measured on the earth's surface, consists of a vertical electric field component and a horizontal magnetic field component each perpendicular to the direction of propagation.

These radio transmitters are very powerful and induce electric currents in conductive bodies thousands of kilometers away. Under normal conditions, the fields produced are relatively uniform in the far field at a large distance (hundreds of kilometers) from the transmitters. The induced currents produce secondary magnetic fields that can be detected at the surface through deviation of the normal radiated field.

The VLF method uses relatively simple instruments and can be a useful reconnaissance tool. Potential targets include tabular conductors in a resistive host rock such as faults in limestone or igneous terrain. The depth of exploration is limited to about 60% to 70% of the skin depth of the surrounding rock or soil. Therefore, the high frequency of the VLF transmitters means that in more conductive environments, the exploration depth is quite shallow; for example, the depth of exploration might be 10 to 12 m in 25 -Ωm material. Additionally, the presence of conductive overburden seriously suppresses response from basement conductors, and relatively small variations in overburden conductivity or thickness can themselves generate significant VLF anomalies. For this reason, VLF is more effective in areas where the host rock is resistive and the overburden is thin.

Karous-Hjelt and Fraser filtering on VLF data:

The KHFFILT program according to Markku Pirttijärvi [15]. can be used to perform Karous-Hjelt and Fraser filtering on geophysical VLF (very-low-frequency) data. In VLF method two orthogonal components of the magnetic field are measured, and normally the tilt angle, a, and ellipticity, *e*, of the vertical magnetic polarization ellipse are derived. Real (in-phase) and imaginary (quadrature) components, however, are traditionally used in Scandinavia and also in KHFFILT program. These components are based on the tilt angle and ellipticity as: *Re*= tan (a).100 % and *Im*= *e*.100 %.

The KHFFILT program requires a PC with 32-bit Windows 9x/NT4/2000/XP operating system and a graphics display of at least 1024´800 resolution. Memory requirements and processor speed and are not critical, since the program uses dynamic memory allocation and the filtering (and contouring) is fast to perform even on slow computers. The KHFFILT program has a simple graphical user interface (GUI) that can be used to change some parameters, to handle file input and output, and to visualize the original and filtered VLF responses. The user interface and the data visualization are based on the DISLIN graphics library.

On startup, the KHFFILT program reads the DISLIN graphics parameters from the KHFFILT.DIS file. If the file cannot be found when the program starts, a new file with default parameter values is created automatically. The program then displays the standard Windows "Open file" dialog to select the VLF input data file. The program then builds up the graphical user and creates the VLF response graph. The three push buttons are used to change the data displayed in the graph area. The "Show data" button selects the original VLF data, "Show Fraser" button displays the Fraser filtered data and "Show K-H contours" displays the Karous-Hjelt filtered pseudosections. Note that since both filtering methods are based on the real component of the VLF data, the program reads only one data component from the input file.

The "Spacing" text field defines the step between profile points. Both Fraser and Karous-Hjelt filtering require that the data have equal distances between the measurement points. To achieve this, the data are always interpolated. The default value is based on the original data (profile length divided by number of points minus one). However, increasing this value will smooth the filtered data and improve the quality of the Karous-Hjelt filtered pseudo-sections in particular. Note also that the "Save VLF data" menu-item saves the interpolated data and not the original data. The "Max depth" and "Skin-depth" text fields are related to Karous-Hjelt filtering. The first one defines the depth extent of the filtering, i.e., the maximum length of the filter. Note that if the data contains several closely spaced conductors, a long filter (large Max depth-value) may not be advantageous because it can combine the two separate targets at large depths. Note also that in VLF method the depth of investigation is typically less than 100 m, so there is no need to use large maximum depth values. The "Skin-

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depth" value defines an additional enhancement by normalizing the currents with the skin depth, i.e., it tries to take the effect of the attenuation of the EM field into account. The value should be based on the skin depth of the host medium (typically between 50-1000 m). The default value is zero, which means that the skin depth normalization is not used at all. The "Update"-button must be used to validate the changes made in the above mentioned text fields [13].

The "Max z-level" and "Min z-level" scroll bars are used to change the scaling of the maximum and minimum contour values in the Karous-Hjelt filtered pseudosection. The contour plot has a fixed number (21) of contour levels. The "Reverse sign" push button reverses the sign of the VLF-data component. Consequently, the sign of the Fraser and Karous-Hjelt filtered data also changes. Note that the sign conventions are not implicit in VLF measurements. For practical reasons, however, it is advantageous to denote conductive targets with positive Fraser and Karous-Hjelt filtered anomalies. The European practice is to use red color for conductive (hot) targets. The "Gray/Color" push button can be used to change between grayscale or color scale (rainbow) in the Karous-Hjelt filtered pseudosections [9].

The Fraser filtering results are stored in two columns that refer to the profile coordinate and the filtered values. The Karous-Hjelt filtering results are stored in three columns that refer to the profile and depth coordinate and the filtered value. Note that the Fraser filtered data does not have the same profile length as the original data, and that the filtered data are placed between the original (or interpolated) data points. Likewise, the profile positions of Karous-Hjelt filtered data are horizontally shifted from depth to depth [9,13,16,15].

MATERIALS AND METHODS

Very Low Frequency (VLF) method:

The equipment used for data acquisition was ABEM WADI. It uses the magnetic components of the electromagnetic field generated by military radio transmitter that uses the VLF frequency band (25-30 kHz) used mostly for long distance communication.

Field Procedures:

VLF instruments may be carried by a single operator and generally weigh 5-10 kg (10-20 pounds). State-of-the-art instruments include software to store the data with survey coordinates, and may be dumped to a laptop computer at the end of the day. Magnetic field measurements do not require ground contact and can be made in less than a minute at each station. Station spacing may vary from 5 to 20 meters (15 to 60 feet) depending on the geologic objective.

The instrument works on the principle of electromagnet induction. When the primary field emitted by a transmitter strikes a body having low electrical resistivity; secondary field is generated in the body. The difference between the transmitted and received electromagnetic field reveals the presence of an anomaly.

RESULTS AND DISCUSSIONS

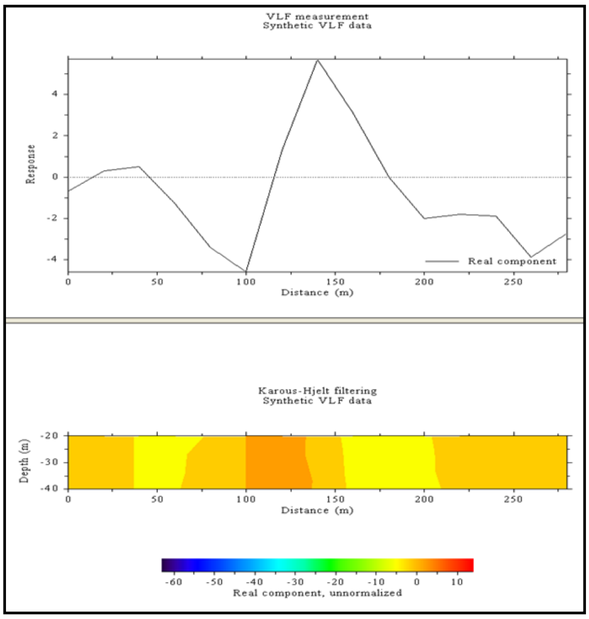

Fig. 3: Karous-Hjelt representation of profile 1.

To the depth of 40 m, this profile of 278 m in the North-South direction is barren of reliable water yield because the conductivity range is between -5 and 0 but from distance 100 m to 140 m, of conductivity range of 0 and 0.3 in the North-South direction which has a good water yield (figure 3).

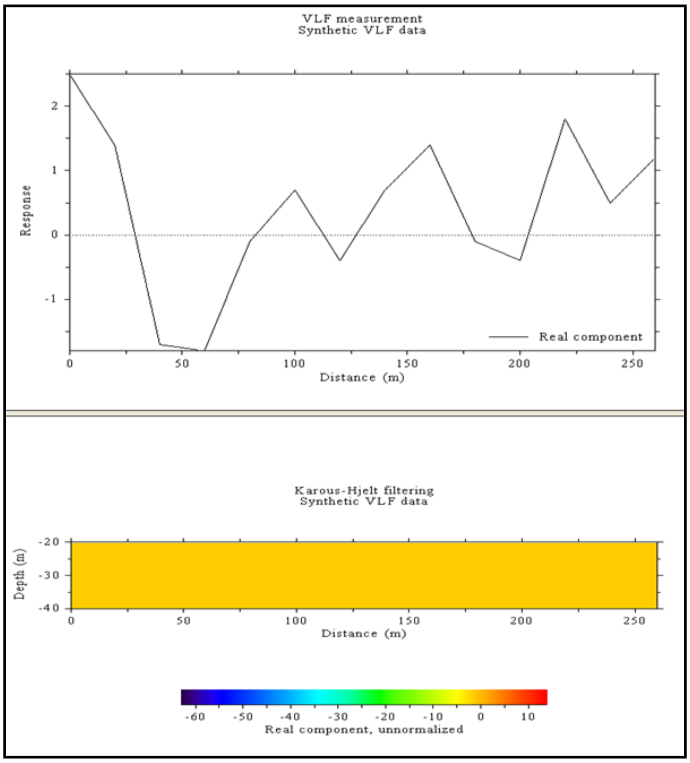

Fig. 4: Karous-Hjelt representation of profile 2.

To the depth of 40 m, this profile of 255 m in North-South direction is barren of reliable water yield because the condutivity range is between -6 and -8 (figure 4).

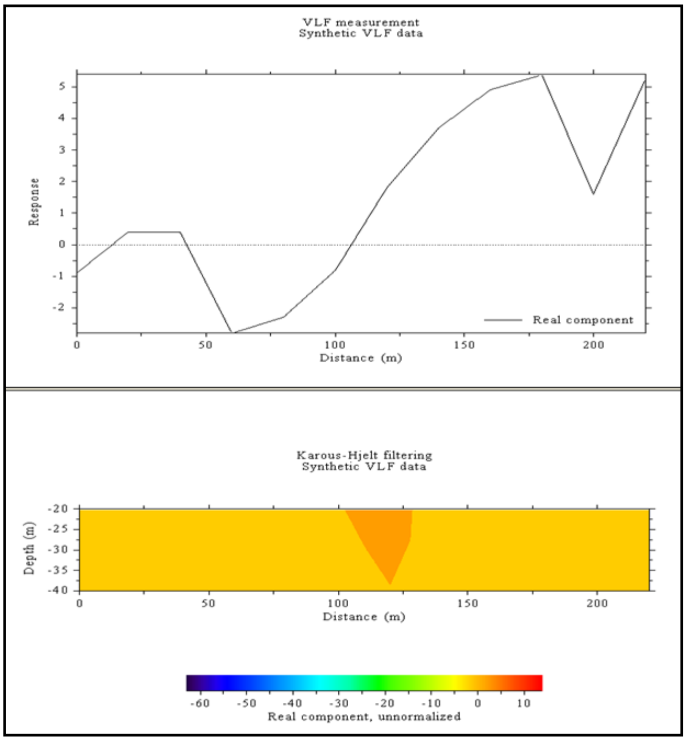

Fig. 5: Karous-Hjelt representation of profile 3.

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To the depth of 40 m, this profile of 220 m in the North-South direction is homogeneously barren of reliable water yield because the condutivity range is between -5 and 0. At distance 120 m in the North-South direction when it is at depth of aproximately 40 m, it has a conductivity range of between 0 and 5 which means a good water yield (figure 5).

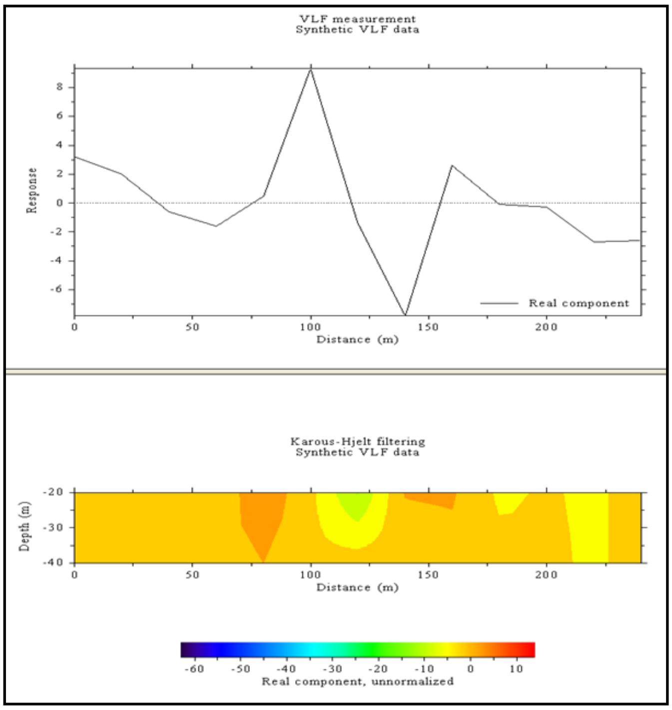

Fig. 6: Karous-Hjelt representation of profile 4.

To the depth of 40 m, this profile of 245 m in the North-South direction is barren of reliable water yield because the conductivity range is between -25 and 0. At distance 80 m in the North-South direction when it is at depth of aproximately 20 m, it has a conductivity range of between 0 and 5 which means a good water yield (figure 6).

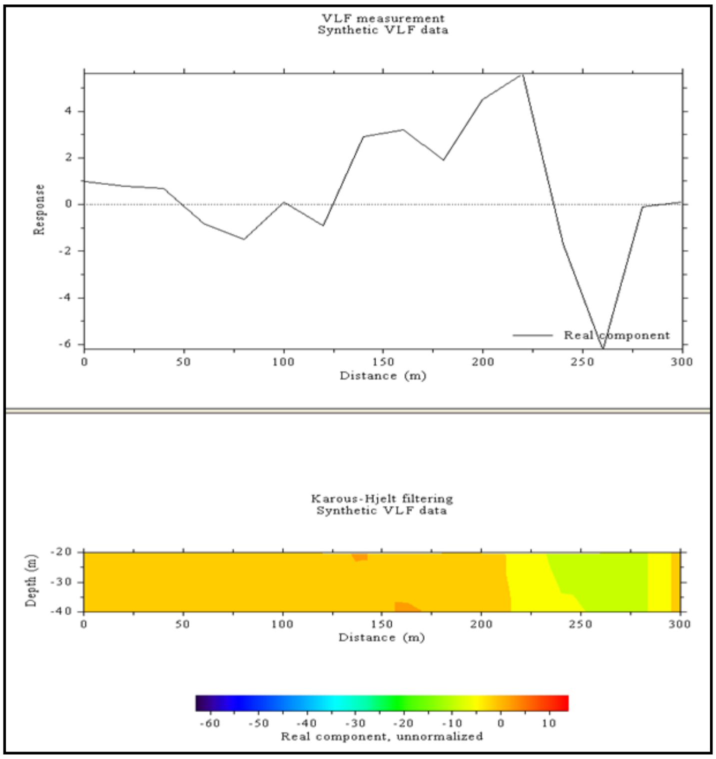

Fig. 7: Karous-Hjelt representation of profile 5.

To the depth of 40 m, this profile of 300 m in the North-South direction is barren of reliable water yield because the conductivity range is between -25 and 0. At distance 165 m in the North-South direction when it is at depth of aproximately 35 m, it has a conductivity range of between 0 and 5 which means a good water yield (figure 7).

Conclusion:

The electromagnetic investigation of Ibodi village, Ilesa, Southwestern Nigeria which was aimed at evaluating the hydro-geological setting of the subsurface with a view to determining the groundwater prospect of the studied area has been undertaken. Five VLF-profiles in the North-South direction of the area investigated were established. VLF at distances (100.0-140.0) m, 40.0 m, 80.0 m and 35.0 m in the North-South directions of the area under investigation of profiles 1, 3, 4 and 5 respectively revealed fractured zones for groundwater exploration in the study area.

Recommendations:

Ibodi village, Ilesa is experiencing development by individuals presently which might lead people to search for groundwater (the best source of water), therefore, the result of this work has been able to reveal the conductive zones which are good for groundwater prospect in the study area.

REFERENCES

[1] Adepelumi, A.A. and O. Fayemi, 2012. Joint application of ground penetrating radar and electrical resistivity measurements for characterization of subsurface stratigraphy in Southwestern Nigeria. J. Geophys. Eng., 9: 397-412.

[2] Akankpo, A.O. and M.U. Igboekwe, 2012. Preliminary Lithologic Deductions for Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria, using Vertical Electrical Sounding Method. Archives of Physics Research, 3(4): 292-302.

[3] Ayodeji, B.O., O. Martins, O.A. Idowu, O.A. Aina and B.A. Akinola, 2012. Determination of Groundwater Availability in Parts of Ilesha, Osun State – An Effort to alleviate the Challenges of Food Insecurity. Special Publication of the Nigerian Association of Hydrological Sciences, pp: 180-187.

[4] Benson, S. and C.R.C. Jones, 1988. The combined EMT/VES geophysical methods for sitting boreholes. Ground water, 26: 54-63

[5] Cosgrove,W.J and F.R. Rijsberman, 2000. World Water Vision. Making Water Everybody's *Busines*s (London: World Water Council, Earth scan publication).

[6] David, O. Omole, 2013. Sustainable Groundwater Exploitation in Nigeria. Journal of Water Resources and Ocean Science, 2(2): 9-14.

[7] Eaton, G.P. and J.S. Watkins, 1970. The use of seismic refraction and gravity methods in hydrogeological investigations. Proc. Canadian Centennial Conf. Mining and Groundwater Geophysics, Ottawa

[8] Foster, S.S.D., 1984. African groundwater developmentthe challenges for hydrogeological science, *in*: Challenges in African Hydrology and water Resources, *Proceedings of the Harare symposium*, July 1984, IAHS publication.

[9] Fraser, D.C., 1969. Contouring of VLF-EM data. Geophysics., 34: 958-967.

[10] Hazell, J.R.T., C.R. Cratchley and A.M. Preston, 1988. The location of aquifers in crystalline rocks and alluvium in Northern Nigeria using combined electromagnetic and resistivity techniques.Quarterly journal of engineering geology, 21: 59-175.

[11] Howard, G and I. Bartram, 2003. Domestic Water Quantity, Service Level and Health (Geneva: World Health Organization).

[12] Jayyousi, O.A., 2007. Water as a Human Right: Towards Civil Society Globalization; International journal of water Resources Development, 23(2): 329-339.

[13] Karous, M. and S.E. Hjelt, 1983. Linear filtering of VLF dip-angle measurements. Geoph. Prospecting., 31: 782-794.

[14] Klein and Lajoie, 1980."Application of geophysical methods to highway related problems" Federal Highway Administrator Central Fedral Lands highways Division lake wood, co, publication no. FHWA-IF-04-021.

[15] Markku Pirttijärvi, 2004. KHFFILT. Karous-Hjelt and Fraser filtering of VLF measurements Version 1.1a.

[16] McNeill, J.D. and V.F. Labson, 1992. Geological mapping using VLF-radio fields: in M.N. Nabighian (Ed.): Electromagnetic methods in applied geophysics, Volume 2, Application. S.E.G.

[17] Olayinka, A.I., S.A. Amidu and M.A. Oladunjoye, 2004. Use of electromagnetic profiling and sounding forgroundwater exploration in the crystalline basement area of Igbeti, Southwestern Nigeria. Global journal of geological sci., 2(2): 243-253.

Journal of Industrial Engineering Research, 1(4) July 2015, Pages: 40-49

[18] Olorunfemi, M.O., M.A. Dan – Hassan and A.S. Ojo, 1995. On the scope and limitations of theelectromagnetic methods in groundwater prospecting in a Precambrian basement terrain a Nigerian case study. Journal of Africa Earth Sciences, 20(2): 151-160.
[19] Onimisi, M., R. Ayuba and A. Daniel, 2014. Electromagnetic Geophysical Prospecting For Groundwater in Basement Complex Terrain: A Case Study of Ola-Oluwa Area of Osun State, Southwestern Nigeria. IOSR Journal of Applied Geology and Geophysics., 2(1): 26-30.
[20] Rahaman, M.A., 1976. Review of Basement Geology of South western Nigeria. In Kogbe, C. A. (Ed.) Geology of Nigeria, Elizabethan publ. Co., Lagos, pp: 41-58.
[21] Spies, B.R., 1989. Depth of investigation in electromagnetic Sounding Methods. Geophysics, 54: 872-888.
[22] United Nations, 2000. United Nations Millennium Declaration. United Nations General Assembly, A/RES/55/2. United Nations : New York.
[23] Vanderberghe, J., 1982, Geoelectric investigations of a fault system in Quaternary deposits. Geophysical prospecting, 30: 879-897.
[24] W.H.O., 2003.. The Right to water, health and Human Rights Publication Series; No. 3 (Geneva: WHO).
[25] Water Aid, Rights and Humanity, 2003. Available at http://www.righttowater .org.uk